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(54) IMPROVEMENTS IN OR RELATING TO THE WEIGHING OF VEHICLES

(71) We, WESTLAND AIRCRAFT LIMITED, of Yeovil, in the County of Somerset, a British Company, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

THIS INVENTION relates to a system for weighing and indicating the position of the centre of gravity of a vehicle, more particularly applied to aircraft, but equally applicable to hovercraft or other forms of road and rail transport.

When, for example, aircraft are operated on miscellaneous duties, generally away from base, involving the frequent carriage of a wide range of mixed cargo, it is extremely difficult to accurately assess the maximum allup/weight and at the same time ensure that the centre of gravity lies within specified safety limits.

In the case of a rotary wing aircraft the power/weight ratio is very important, and any overloading manifests itself in a loss of performance and the danger of subsequent high torque loading on the transmission, ultimately resulting in fatigue.

It is, therefore, an object of the invention to provide a system which will overcome this problem by giving the vehicle operator a direct indication of weight and centre of gravity shift while cargo loading is taking place.

According to the invention we provide a weight and centre of gravity determination system for a vehicle the said system including a plurality of load sensing elements attached to the vehicle structure at predetermined positions relative to a selected datum and responsive to variations in vehicle loading to transmit electrical output signals to electronic circuits, wherein the electronic circuits sum the electrical output signals and transmit the resultant to a vehicle weight indicator, and convert the separate electrical signals of varying magnitude to moments about the selected datum and transmit the moments in the form of electrical signals to a centre of gravity displacement indicator.

In any aircraft, there are at least three attachment points between the airframe and the undercarriage which can be used to contain load sensing elements. In a preferred system, three load sensing elements are used, the electrical output signals from which are used to compute the all-up weight and the position of the centre of gravity. A fixed allowance is made for the weight of the undercarriage structure which is below the load sensing elements.

In Figure 1, a plan view is shown of a schematic layout of three load sensing elements in a theoretical aircraft.

The output of each load sensing element in volts is calibrated against applied load.

To compute the all-up weight, the output of the three load sensing elements is added arithmetically.

Let W=weight of the aircraft which is acting at the point F.

w_1=weight supported at load sensor position A.

w_2=weight supported at load sensor position B.

w_3=weight supported at load sensor position C.

v_1=output voltage from load sensor A.

v_2=output voltage from load sensor B.

v_3=output voltage from load sensor C.

$W=w_1+w_2+w_3$

Then

$$v_1 \propto w_1 \qquad v_1=k_1w_1$$
$$v_2 \propto w_2 \qquad v_2=k_2w_2$$
$$v_3 \propto w_3 \qquad v_3=k_3w_3$$

Where k_1, k_2 and k_3 are the calibration

[*Price 25p*]

constants of the three load sensing elements. Then the all-up weight

$$W \propto v_1+v_2+v_3 \qquad \ldots\ (1)$$

In Figure 1, the optimum position of the C. of G. is shown at O, which is the origin of a co-ordinate system with two perpendicular axes OX and OY in the horizontal plane. Suppose the actual C. of G. position is at a point F, which has the co-ordinates $(\bar{x}, \bar{y})$.

The weight of the aircraft W is assumed to act vertically through F.

Let the co-ordinates of the load sensing element at A be $(-x_1, y_1)$.

Let the co-ordinates of the load sensing element at B be (x_2, y_2).

Let the co-ordinates of the load sensing element at C be $(x_3, -y_3)$.

Then, by taking moments about the OY and OX axes,

$$\bar{x}=\frac{\Sigma wx}{\Sigma w} \text{ and } \bar{y}=\frac{\Sigma wy}{\Sigma w}$$

Therefore:

$$\bar{x}=\frac{-x_1w_1+x_2w_2+x_3w_3}{w_1+w_2+w_3}$$

Since the positions A and B are symmetrical about the centreline of the aircraft, and since position C is on the centreline,

$$x_1=x_2 \text{ and } x_3=0$$

Let

$$x_1=x_2=a$$

Therefore:

$$\bar{x}=\frac{a(w_2-w_1)}{(w_1+w_2+w_3)} \qquad \ldots\ (2)$$

$$\bar{y}=\frac{w_1y_1+w_2y_2-w_3y_3}{(w_1+w_2+w_3)}$$

again, due to the symmetry of the undercarriage, $y_1=y_2$.

Let

$$y_1=y_2=(j-h) \text{ and } y_3=h$$

Therefore:

$$\bar{y}=\frac{(j-h)(w_1+w_2)-w_3h}{(w_1+w_2+w_3)}$$

Therefore:

$$\bar{y}=\frac{j(w_1+w_2)}{(w_1+w_2+w_3)}-h \qquad \ldots\ (3)$$

The electronics unit is now required to receive inputs from the load sensing elements as voltages v_1, v_2 and v_3, and produce an output voltage proportional to $\bar{x}$, to display on the lateral C. of G. position indicator, and a voltage proportional to $\bar{y}$, to display on the fore and aft C. of G. position indicator. The two meters have centre zero movements and use a +ve and −ve sign convention.

Hence:

$$\bar{x}=\frac{K_4(v_2-v_1)}{(v_1+v_2+v_3)}$$

where K_4 is a constant proportional to the distance a between the two forward sensors.

$$\bar{y}=\frac{K_5(v_1+v_2)}{(v_1+v_2+v_3)}-K_6$$

Where K_5 is a constant proportional to the distance j in Fig. 1 and K_6 is a constant proportional to distance h.

The block diagram, Figure 2, shows as an example an operational layout for the described theoretical system with additional circuitry shown in broken line. These additions include a fourth load sensing element (D) to measure the load carried on a cargo hook; the signal obtained from this load sensing element is passed through an amplifier 20 to a separate cargo hook load indicator 21, and/or for display on the all-up weight indicator (A.U.W.) 22. A second modification includes an overload or heavy landing trip circuit 23 plus its indicator 24, which could be set to operate when a predetermined load level is exceeded. This trip circuit might be set to operate when the maximum all-up weight of the aircraft is exceeded, or when a heavy landing is experienced, causing loads in the undercarriage which exceed this predetermined load level. A final addition to this layout is the inclusion of an A.U.W. "hold" switch 25, which enables the pilot to retain a permanent indication during flight, of take-off weight. The remainder of the block diagram shows the three load sensing elements, A, B and C, various summing amplifiers with differential inputs for obtaining addition and subtraction terms, active dividers, and a centre of gravity displacement indicator 26.

The preferred embodiment is also described with reference to the block diagram

of Figure 3, which shows a variation of Figures 1 and 2.

The disclosed system is one comprising three or four load sensing elements 2, built either into an aircraft's undercarriage or into the undercarriage supports. These load sensing elements would only be removed for recalibration and servicing at major overhauls, and would otherwise require no attention whatsoever. The load sensing elements would be energised from the main aircraft supply 1, or from a separate generator.

As the aircraft is being loaded, the additional weight imposes a certain amount of strain into the aircraft undercarriage, and this strain is sensed by the load sensing elements which in turn transmit an electrical signal indicating this increase in strain via amplification units 3 to a summing amplifier 4, which adds the outputs of all the load sensing elements 2 used in the system and presents the weight as a total on indicator 5.

The indication of movement of the position of the centre of gravity is achieved by using the weights previously measured by load sensing elements 2, and converting these weight signals to moments about an axis dependent on the distance between the load sensing elements and the datum point of the weighing system. This is carried out by multiplier units 6, into which are fed the weight signals from the amplifiers 3, and the distance signals indicated as coming from numerals 7. The accumulated moment signals from multipliers 6 are added in summing amplifier 8, the resultant signal being passed then to an electronic divider 9, which divides this signal by the signal produced, indicative of the total weight, from summing amplifier 4. The process of taking moments is carried out in the fore and aft direction and also in the port and starboard direction. This is shown in the circuitry in Figure 3, in which the two sets of multiplier units 6 are supplied with weight signals from the amplifiers 3 and the port/starboard and forward/aft distance signals respectively. The result from both circuits can be presented, as shown by two indicators 10 and 10(A), in the form of a shift from the nominal or ideal position in the port/starboard direction, and also in the forward/aft direction, or the results from both circuits could be integrated to indicate the positional change of the centre of gravity in planform on a two axis instrument, the face of the instrument giving a plan of the allowable region of change.

Other modifications can be made to the system without altering the basic concept of the invention, for example, after the initial signals from the load sensing elements are amplified and summed, a pendulum or gyro-type attitude-compensating transducer may be introduced to make allowance for the aircraft or vehicle's attitude, so that the true C.G. position in the horizontal plane can be presented to the pilot in addition to the weight. To increase the accuracy of the system it may be required to introduce a zeroing circuit, whereby the operator or pilot, knowing his basic weight, is able to zero the instrumentation before loading with cargo. A subsidiary circuit and indicator could be interconnected which gives the pilot a double check on fuel contents during refuelling and would be responsive to weight increases due to fuel intake.

The load sensing elements could be bonded foil strain gauges, resistance wire gauges, load cells, piezo-electric transducers, or any other form of strain gauge transducer. They may be attached to the vehicle, or integrally built into the vehicle structure. The load sensing elements are capable of bearing load and when subjected to compression, tension, bending, shear, and torsional forces, are capable, in each mode, of providing output signals that will be proportional to the load carried.

It is important that the elements be positioned such that there is no possibility of any of the vehicle's weight bypassing them.

As previously indicated, the cargo hook on a helicopter could be strain gauged, and "plugged" into the system to give the pilot an indication when the maximum safe load for his cargo sling is reached.

A heavy landing indicator for aircraft has also been envisaged where the maximum shock load on any one load cell is registered on the instrument, or recorded in some suitable manner within the electronic unit with a warning light adjacent to the instrument panel. The advantage of this system would be as a warning indication of the necessity of inspection requirements, if the normal stressing limits were exceeded.

It must be understood that this invention is not limited to any particular type of vehicle, and its scope could embrace heavy lorries, cars, rail transport, fixed wing aircraft, and hovercraft.

WHAT WE CLAIM IS:—

1. A weight and centre of gravity determination system for a vehicle, the system including a plurality of load sensing elements attached to the vehicle structure at predetermined positions relative to a selected datum and responsive to variations in vehicle loading to transmit electrical output signals to electronic circuits, wherein the electronic circuits sum the electrical output signals and transmit the resultant to a vehicle weight indicator, and convert the separate electrical output signals of varying magnitudes to moments about the selected datum and transmit the moments in the form of electrical signals to a centre of gravity displacement indicator.

2. A system as claimed in Claim 1, wherein the electronic circuits comprise a first and two second electronic circuits, the first circuit providing electrical signals to operate the vehicle weight indicator and the second circuits providing electrical signals to operate the centre of gravity displacement indicator, one of the second circuits providing indication of centre of gravity displacement in the lateral direction and the remaining second circuit providing indication of centre of gravity displacement in the fore-and-aft direction.

3. A system as claimed in Claim 2, wherein the first electronic circuit comprises amplification units corresponding in number to the number of load sensing elements and a summing amplifier, each of the second circuits comprising multiplier units, a summing amplifier and an electronic divider, the multiplier units in each circuit corresponding in number to the number of load sensing elements and arranged to receive signals corresponding to both the load and to displacement from the datum in the lateral and fore-and-aft directions respectively.

4. A system as claimed in any preceding Claim, wherein three load sensing elements are provided on the vehicle structure.

5. A system as claimed in any preceding Claim, wherein the load sensing elements are bonded foil strain gauges.

6. A system as claimed in any of Claims 1 to 4, wherein the load sensing elements are strain gauge load cells.

7. A system as claimed in any preceding Claim, wherein the vehicle structure is the landing gear of an aircraft.

8. A system as claimed in any preceding Claim, wherein the load sensing elements are formed integral with the vehicle structure.

9. A system substantially as hereinbefore described with reference to the accompanying drawings.

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1226214 COMPLETE SPECIFICATION

3 SHEETS *This drawing is a reproduction of the Original on a reduced scale*

Sheet 1

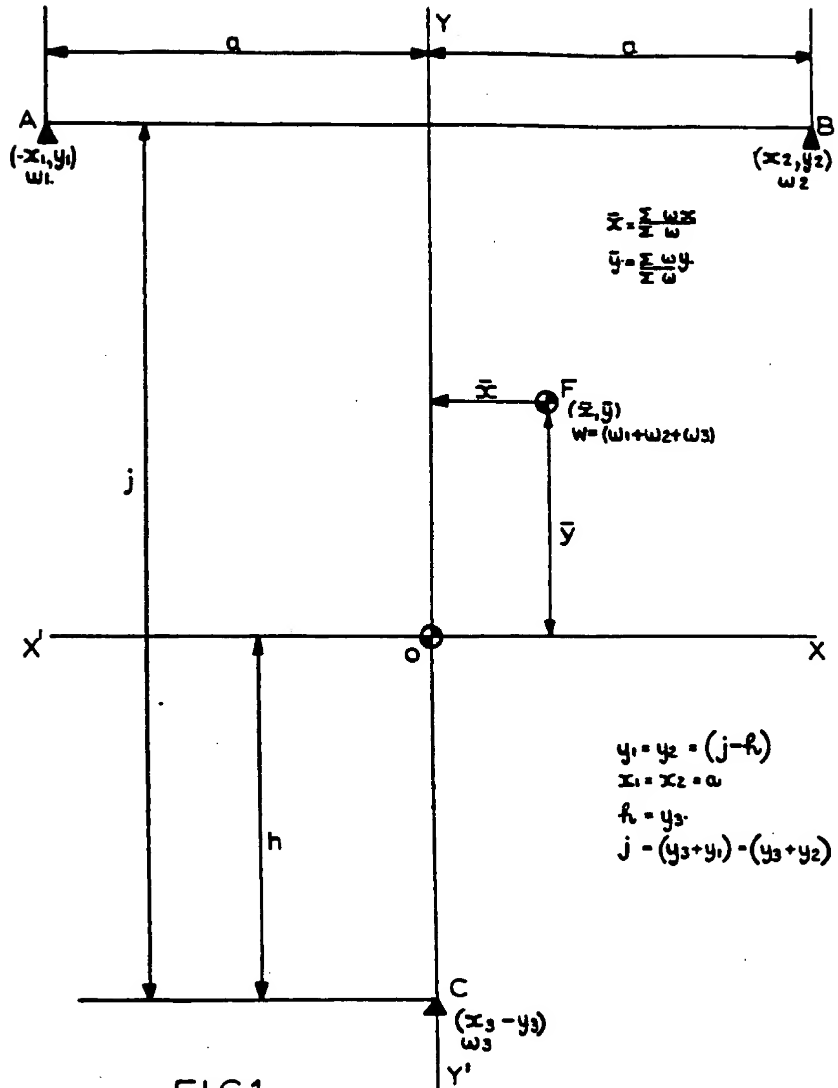

FIG.1

1226214 COMPLETE SPECIFICATION

3 SHEETS *This drawing is a reproduction of the Original on a reduced scale*

Sheet 2

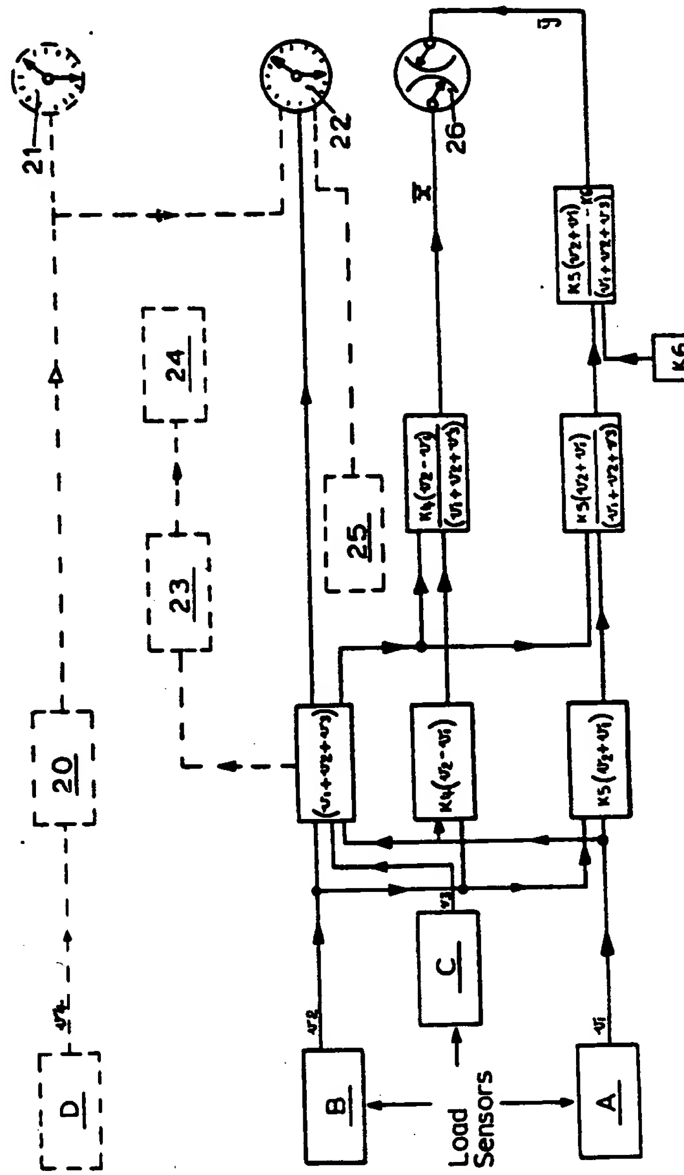

FIG.2

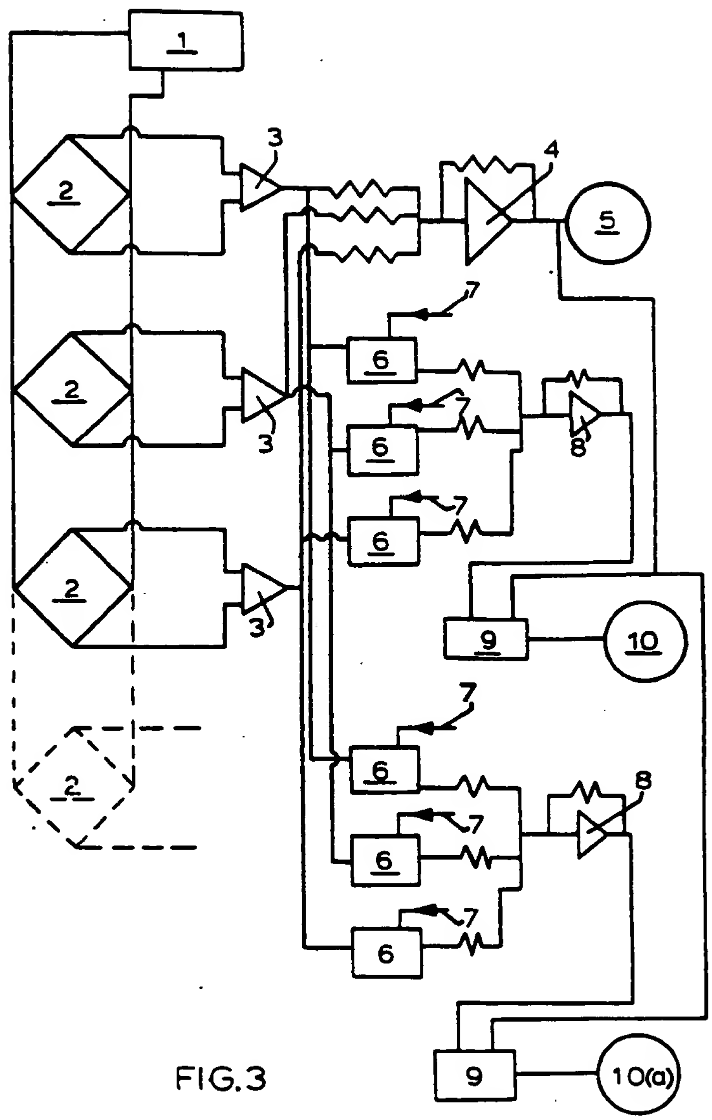

FIG.3